

Environmental Status of Urban Beaches in São Luís (Amazon Coast, Brazil)

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ABSTRACT

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The city of São Luís is situated in the Amazon littoral and was declared a World Cultural Heritage by UNESCO. In the last decades, the urban growth along this coast has caused serious environmental problems. In this context, this work presents environmental conditions in four urban beaches of São Luís. Coast mapping, survey of private and public services and infrastructure, and hydrodynamic and hydrological measurements were carried out in Ponta de Areia, São Marcos, Calhau and Olho d'água beaches. Results showed irregular occupation on dunes and cliff zones. The beaches have good private services, but offer inefficient public services, e.g., sanitary systems. Irregular occupation and lack of an efficient sanitary system are responsible for the main environmental problems. In these dissipative macro-tidal beaches, around 300m width and with a dominance of tidal currents, erosive problems have destroyed some constructions and infrastructure. Therefore, coastal protection structures can be observed in the most affected zones. The presence of more than a hundred wastewater outflows along these beaches has affected their water quality (in terms of fecal coliforms) and consequently the health of the users. The beaches situated near São Luís downtown (Ponta de Areia, São Marcos and Calhau) are the most frequented by users due to easy access, but are the most affected (most occupied, eroded and polluted), showing the necessity of coastal management actions to guarantee the overall quality of one of the most urbanized areas of the Amazon coast.

ADDITIONAL INDEX WORDS: *Beaches, Amazon Littoral, Brazil.*

INTRODUCTION

The Brazilian coastline has an extension of 8,500km, where different coastal ecosystems can be found (beaches, mangroves, estuaries, dunes and others), including almost 50% of the country's population, which is distributed among 400 municipalities (CUNHA, 2005). The Amazon coast contains about 35% of the Brazilian coastline (ISAAC and BARTHEM, 1995). It is characterized by the presence of a wide continental shelf (up to 330km), a unique macro-tidal regime (reaching maximal heights of 8m in Maranhão, 6m in Pará and 11m in Amapá), high annual precipitation (up to 3300mm), a wide mangrove system (85% of Brazil's mangrove area), and the highest fluvial discharge worldwide (Amazon River). The presence of many estuaries, wide areas with difficult means of access, as well as the presence of three important urban centers (Macapá, Belém and São Luís), and some conservation units also defines this zone.

In the small coastal villages of this zone, human activities are based mainly on familiar agriculture and fishing (subsistence and commercial), while in the biggest urban centers, industry, harbors, fishing and tourism are the principal activities (IBGE, 2007). The lack of planning with regard to territorial occupation, high population growth, inadequate services and infrastructure, and illegal exploration of natural resources are responsible for many

social and environmental conflicts that affect the health of Amazon coastal ecosystems (KRAUSE and GLASER, 2003; PEREIRA *et al.*, 2007a).

Situated in the Amazon littoral, São Luís is one of the most populous Amazon zones, and, consequently, it is one of the most affected by human activities. This city is located in the coastal zone of Maranhão State (NE, Brazil) and was declared a World Cultural Heritage site by UNESCO in 1997 due to its great historical and cultural value. Traditionally, the São Luís coast has been widely used for leisure, fishing, tourism and building activities. Since the beginning of the 1970s, use of the beaches has increased mainly due to irregular occupation on the dunes and cliff zones, which has resulted in serious marine erosion. Together with other problems related to the lack of adequate services/infrastructure, this increase in use has compromised the beach quality and decreased the ability of people to enjoy the beaches.

The main aim of this study was to characterize environmental conditions of the São Luís littoral through coastal mapping, surveys of private and public services/infrastructure, and measurement of hydrodynamic and hydrological parameters. The results obtained may be used by local administrations and could be useful in development/implementation of coastal management plans.

STUDY AREA

This study was carried out in four urban beaches of the Amazon littoral (Figure 1) situated along the waterfront of São Luís city (Ponta de Areia, São Marcos, Calhau and Olho d'água). The coastal zone of São Luís has high energy and is dominated by a semidiurnal macro-tidal regime with a maximum tidal height of 8 m during the equinoctial spring tide (DHN, 2008).

The climate is AW type according to the Köppen system (Rainy Tropical) with two main seasons, the wet season and the dry season. The dry season, which normally spans June to November,

is characterized by a mean rainfall of up to 200mm and temperatures up to 33°C. The wet season, which spans from December to May, is characterized by a mean rainfall that exceeds 1500mm and temperatures falling to a minimum of 20°C. The wind climate shows a seasonal pattern, with the strongest winds blowing during the dry season, mainly between August and January (mainly NE winds with mean values of up to 4.0m/s), and moderate winds blowing during the rainy season, mainly between March and July (mean values of up to 3.5m/s) (PORTO DE ITAQUI, 2008).

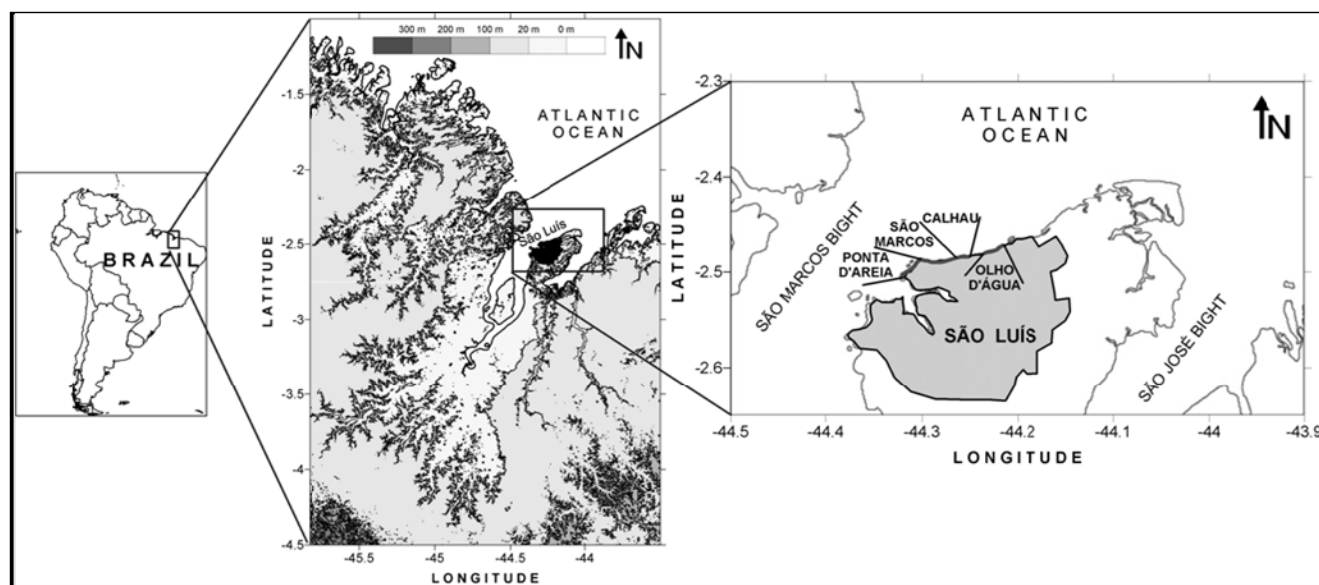


Figure 2. Study area and location of evaluated beaches.

São Luís city has a total population of about 958,000 inhabitants (IBGE, 2007), and part of it is located on the São Luís island in the São Marcos Bight. The local economy is based mainly on industry and commerce, but tourism has been growing annually. The studied beaches are situated in a risk area due to their proximity to the Itaqui harbor (one of the largest harbors in the world). This harbor is affected by accidents with oil and other contaminants. Regional climatic conditions and human-induced modifications of the beaches (e.g., inadequate territorial occupation, presence of illegal domestic sewage outfalls) are the main factors responsible for the decrease in beach quality in the studied area.

METHODS

This work was carried out during two periods, September 2007 (dry period) and April 2008 (rainy period). One portable GPS was used for coastal mapping along the 12km of littoral. Areas were classified as occupied (cliff, dune, intertidal and dune zones) or not occupied. Informal interviews and a check list were used to evaluate the type, amount and quality of private and public services/infrastructure accessible to beach users.

Hydrodynamic (wave, tide and currents), geological (topographic leveling and sedimentology), hydrological (physical, chemical and microbiological) and socioeconomic studies were performed in the four studied beaches. A mini-current meter

(Sensordata SD 6000), a wave and tide data logger (TWR-2050) and a CTD (XR-420) were anchored in each of the studied beaches for 13h in each period.

Four topographic leveling profiles were carried out, and surface sediment samples were gathered along these beach profiles during the two periods. Grain sizes were submitted to statistical analysis according to FOLK and WARD (1957). The morphodynamic conditions were determined according to WRIGHT and SHORT (1984) and MASSELINK and SHORT (1993).

Hydrological data were obtained from analysis of water samples collected with Niskin oceanographic bottles during ebb and flood tide periods. The main variables were turbidity, pH, dissolved oxygen, dissolved nutrients (nitrite, nitrate, phosphate and silicate), chlorophyll *a* and fecal coliforms. Turbidity was measured by a turbidimeter and the pH by an electronic pH meter. Dissolved oxygen was determined by the WINKLER method, as described by STRICKLAND and PARSONS (1968), dissolved nutrient salts were determined according to STRICKLAND and PARSONS (1972) and GRASSHOFF *et al.* (1983) and chlorophyll *a* for STRICKLAND and PARSONS (1972). Fecal coliforms were determined following the AMERICAN PUBLIC HEALTH ASSOCIATION guidelines (2007).

RESULTS AND DISCUSSION

Territorial Occupation

All studied beaches have easy access, especially those situated near downtown São Luís (Ponta de Areia, São Marcos and Calhau). Houses, hotels, restaurants, bars, residential and commercial buildings, marine via, and marine walk are present on dunes and intertidal and/or cliff zones along the studied littoral. The most occupied beach is São Marcos, and the least occupied is Calhau (Table 1).

Table 1. Territorial occupation (%) along the studied zone. PA- Ponta de Areia, SM- São Marcos, C- Calhau, OA- Olho d'água.

OCCUPATION	PA	SM	C	OA
Dune zones	69	64	18	59
Dune and Inter-tidal zones	0	0	41	10
Cliff zone	0	15	0	0
Not occupied	31	21	41	31

The studied area is situated in one of the most urban zones of the Amazon littoral, but territorial occupation on dune zones, cliff or intertidal zones is not allowed by the State and Federal laws (number 4669 Oct 2006 and number 7.661,16 May 1988, respectively). In addition, high buildings hinder local air circulation and simultaneously shade the beach from direct sun light in the afternoon hours. Irregular construction is also observed in other beaches of the Amazon littoral as well as in mangrove ecosystems (PEREIRA *et al.*, 2007a).

Ponta de Areia beach is mainly used for fishing, sea bathing and other kinds of leisure, while the other beaches are used for fishing, sea bathing, and aquatic sports (surfing, raid-surfing, kite surfing, windsurfing).

More numerous and higher quality facilities are available at São Marcos and Calhau (Table 2). This imbalanced distribution reflects economic differences in the area and the profiles of the beach users. Using lamp posts as an index of security, São Marcos and Calhau beaches can be considered a safer zone. Free public services, such as phones and parks, are also concentrated in this area, reflecting the “degree of interest” of the administration in one specific part of the São Luís littoral and, on the other hand, the high affluence of the people in this region with a better economic profile.

The best private services, such as showers, bars/restaurants, water sport rental services and ground sports, are also located in São Marcos and Calhau (Table 2). This distinction reflects the spatial distribution of the number and economic profile of beach users, because the main objective of these services is to obtain an economic profit.

Some studies of beach users' perceptions show that the choice of a beach by people with a better economic profile depends on the efficiency of the services and infrastructure (ROCA and VILLARES, 2008; others).

The inefficiency of a basic sanitary system in São Luís is indicated by the presence of 101 sewage outfalls along the four studied beaches. These clandestine discharges are one of the most serious problems affecting the health of the users and the beach quality, especially during weekends, when beach attendance is higher. The highest number of sewage outfalls was found in Ponta da Areia (N=47), followed by São Marcos (N=36), Calhau (N=15) and Olho d'água (N=13). In São Luís city, only 50% of the residences are connected to a basic sanitary system (IBGE, 2007).

Along the littoral of São Luís, Calhau is the only beach presenting partial sanitary service, while in the other beaches, this service is practically nonexistent (ESPÍRITO SANTO, 2006).

The movement of cars is prohibited in the intertidal zones, except in Olho d'água. The presence of vehicles in this beach is responsible for traffic problems and can be considered a serious risk to the beach users, mainly during weekends in the dry season, when beach attendance is higher. This situation was also observed in other beaches of the Brazilian Amazon littoral, including the Ajuruteua beach in the Pará State (PEREIRA *et al.*, 2006).

Environmental Factors

Physical, chemical and biological data show that the beaches of São Luís are strongly affected by the climatological regime and human activities. Hydrodynamic data show a predominance of

Table 2. Spatial distribution of facilities in the study area. PA- Ponta de Areia, SM- São Marcos, C- Calhau, OA- Olho d'água.

Facilities	PA	SM	C	OA
Garbage baskets	48	45	50	10
Lamp posts	26	87	115	39
Lifeguard/Municipal guard	01	01	01	01
Public phones	04	13	19	05
Public toilet	02	0	0	0
Private showers	0	09	10	0
Water-sport renting	0	02	0	04
Private soccer/volley fields	0	0	02	0
Bars/Restaurants	41	30	36	48
Hotel/Hostal	12	0	05	04
Reggae Club	02	0	0	0
Park Public	0	01	01	0
Historic point	01	01	0	0

high energy conditions, mainly in September 2007 (dry period), which are characterized by strong tidal currents (up to 1.2m/s), a high tidal range (up to 6.5m), wave periods lower than 8 s and maximum height waves, H_b, up to 1.1m as a consequence of the high wind intensities (3.85m/s). São Luís has tide-modified beaches because the obtained RTR values were between 3 and 15 with dissipative characteristic (Table 3). As a consequence of the strong winds in September 2007, the aeolian sediment transport was responsible for the accretion condition in this period (Figure 2). But, erosive problems in the most occupied zones were observed along the four studied beaches. The most exposed beach was Olho d'água, and the most sheltered was Ponta de Areia. These are macrotidal dissipative beaches that are mainly covered by well-sorted and leptokurtic quartz fine sands.

During the dry season, the highest salinity, temperature, dissolved oxygen and pH values were registered, mainly during the flood tide period. In the same season, nitrite, silicate and chlorophyll *a* concentrations were higher, mainly in the ebb tide period (Table 4). During the rainy season, the highest turbidity and nitrate concentrations were observed (Table 4). Phosphate concentrations presented similar trends in the two periods, and fecal coliforms showed high values throughout the study period, except in Olho d'água (Table 4).

The high rainfall rates commonly found in the equatorial zone were responsible for the lowest salinity, temperature and pH values observed during the rainy season (April 2008).

The highest dissolved oxygen concentrations during the dry season (September 2007) indicated a high local hydrodynamic regime. The turbidity was elevated due to the estuarine discharge and the high hydrodynamic energy along this littoral, which is responsible for the re-suspension and transport of fine sediments in the water column.

High nutrient concentrations were found during the rainy and dry seasons due to the river run-off and sewage outfalls, which contribute to the occurrence of high chlorophyll *a* concentrations. Blooms of dinoflagellates and Chlorophyta on the sand, in the intertidal zone, were observed during the two seasons along four beaches near the sewage outfalls.

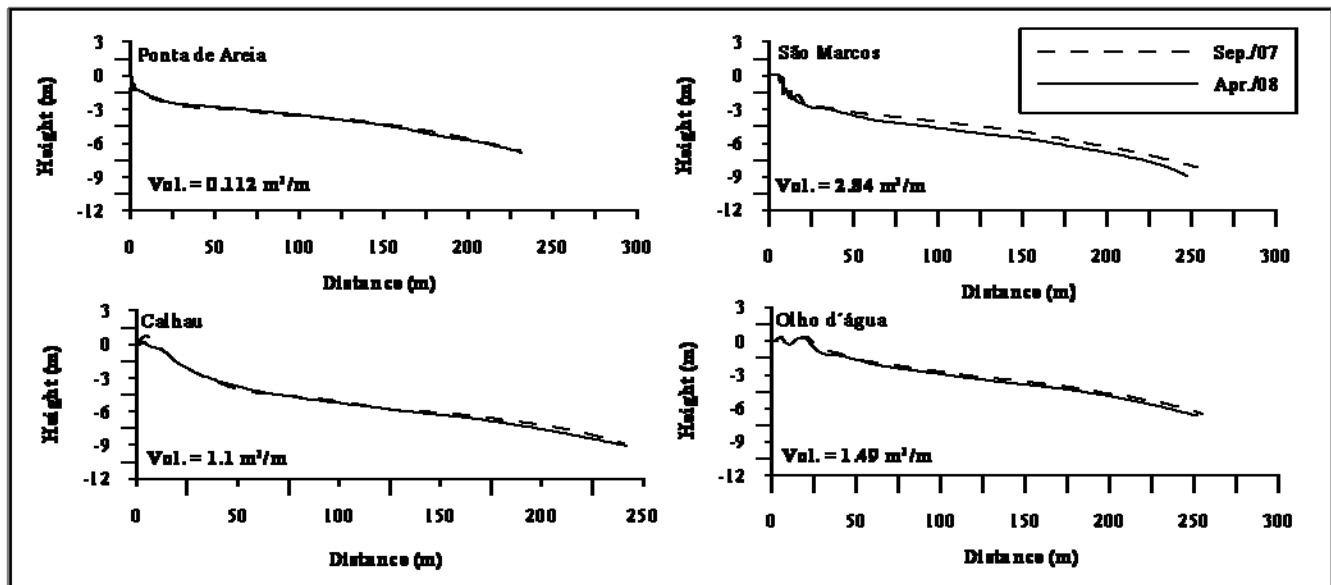


Figure 2. Beach Morphology.

Table 3. Morphodynamic conditions in São Luís beaches.

Beaches	Months	TR	H _b (m)	T(s)	RTR	Ω	Cur.(m/s)
Ponta de Areia	Sep/07	5.6	0.84	3.1	6.67	11.3	1.0
	Apr/08	6.5	0.35	7.6	18.6	1.9	0.8
São Marcos	Sep/07	5.9	0.87	4.4	6.78	8.2	1.2
	Apr/08	6.4	0.66	7.9	9.7	3.5	0.9
Calhau	Sep/07	6.2	1.0	3.7	6.20	11.3	1.2
	Apr/08	6.2	0.54	6.6	11.5	3.4	0.8
Olho d'água	Sep/07	6.4	1.07	5.0	5.98	8.9	1.9
	Apr/08	6.0	0.71	7.7	8.45	3.8	0.9

The presence of several clandestine sewage outfalls has affected beach quality and elevated the dissolved nutrient concentrations and fecal coliform numbers. They reflect the degrading state of these beaches. The lack of public interest in improvement of this service is evident, and the fast building growth observed in some zones can aggravate this problem.

The high observed hydrodynamics has prevented an increase in the risk of beach and beach users' contamination because the sewage launched in the intertidal zone is washed and diluted by seawater during the flood tide. In sheltered beaches in the Brazilian northeast, the presence of sewage outfalls was responsible for serious social, economic and environmental problems in beaches situated in Olinda littoral (included in UNESCO's World Heritage List in 1982) (PEREIRA *et al.*, 2007b).

Table 4. Hydrological parameters in São Luís beaches. ET- ebb tide and FT- flood tide.

Beaches	Periods	Tide	Temp. (°C)	Sal. (psu)	pH	O ₂ (mg/l)	Turb. (UT)	NO ₂ (mg/l)	NO ₃ (mg/l)	PO ₄ (mg/l)	SiO ₂ (mg/l)	Chl <i>a</i> (mg/m ³)	Fec. Col. (MPN)
Ponta de Areia	Sep/07	ET	29.0	37.1	8.21	7.6	39.29	0.029	0.012	0.017	2.227	8.316	>1100
		FT	29.8	36.5	8.38	7.7	22	0.028	0.009	0.018	2.355	2.157	>1100
	Apr/08	ET	30.1	25.7	7.79	4.8	54	0.005	0.106	0.017	2.453	8.567	>1100
		FT	29.6	25.3	8.02	5.4	200	0.004	0.293	0.020	3.146	0.406	>1100
São Marcos	Sep/07	ET	29.2	36.7	8.30	7.4	15.39	0.036	0.012	0.019	2.203	2.720	>1100
		FT	29.7	37	8.40	7.3	17.78	0.029	0.011	0.017	1.859	3.717	>1100
	Apr/08	ET	30.6	25.2	7.85	5.1	131	0.007	0.1	0.015	2.365	4.836	>1100
		FT	29.1	25.3	8.01	5.4	149	0.005	0.082	0.015	2.188	4.355	>1100
Calhau	Sep/07	ET	29.0	36.6	8.26	7.5	16.38	0.026	0.012	0.017	2.016	4.582	>1100
		FT	29.2	36.5	8.38	7.5	26.60	0.007	0.011	0.018	1.869	2.621	>1100
	Apr/08	ET	31.0	24.9	7.95	4.9	85	0.009	0.1	0.016	2.522	1.334	>1100
		FT	29.6	25.1	8.02	5.6	88	0.006	0.094	0.017	1.810	2.563	>1100
Olho d'água	Sep/07	ET	29.0	35.8	8.38	7.5	14.80	0.077	0.002	0.014	2.497	6.982	>1100
		FT	29.0	36.7	8.37	7.6	30.88	0.008	0.012	0.017	1.869	0.196	150
	Apr/08	ET	30.7	24.6	7.94	4.6	55	0.008	0.108	0.015	2.596	4.002	150
		FT	29.4	25.1	8.02	5.7	85	0.007	0.136	0.02	2.252	0.406	460

FINAL CONSIDERATIONS

Private infrastructure and services seem to be sufficient for beach users, but some public services, such as basic hydric canalization, are absent. The presence of several clandestine sewage outfalls has affected the beach quality (in terms of water and sand contamination and visual/odor) and represents a serious risk for human health (occurrence of mycosis and other illnesses). In addition, irregular territorial occupation has been causing serious environmental problems, mainly in the most occupied zones, which consequently are the most polluted in terms of fecal coliforms.

Therefore, coastal management actions are necessary to guarantee the overall quality of one of the most urbanized areas of the Amazon coast. The authors suggest several actions that could be undertaken by governmental authorities to improve the status of São Luís beaches: (i) to remove all sewage or pluvial outfalls and their connection to the principal web, (ii) control of the new wastewater inputs to the beaches, (iii) increased numbers and improvement of public facilities (services and infrastructure), (iv) the development of a sanitary and environmental education program, (v) elaboration of a plan for the protection of dunes and cliff zones, (vi) monitoring of some environmental indicators, such as fecal coliforms, to inform users about the water quality of the studied beaches.

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